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THESIS

EVALUATION OF
THE MPA DETECTION AND ALLOCATION MODELS
UTILIZED BY
THE ASW SYSTEMS EVALUATION TOOL (ASSET)

by

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by

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The primary objective of this thesis is to analyze and recommend improvements to the Maritime Patrol Aircraft (MPA) detection and allocation models utilized by the ASW Systems Evaluation Tool (ASSET), version 1.0. ASSET is a generic high-level ASW modeling tool, designed to aid CNO (OP-71) in the development and refinement of ASW top-level warfare requirements and the ASW Master Plan. ASSET's strengths lie in its C^3I modeling of submarine, MPA, and overhead surveillance in large scale ASW campaigns. To reduce the processing time required by ASSET, the current version of the MPA detection model contains simplifications which can limit its ability to effectively simulate some MPA tactical ASW scenarios. This thesis proposes two new MPA detection models which utilize the coverage area of a user-defined sonobuoy pattern and address the limitations of the current ASSET model. Also proposed is an MPA allocation scheme which should provide a higher cumulative detection probability.

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I. INTRODUCTION

The Naval Postgraduate School (NPS) was tasked by CNO (OP-71) to evaluate the ASW Systems Evaluation Tool (ASSET) which was developed by Metron, Inc. This thesis report is one of several evaluations conducted on the various sub-models of ASSET. Many versions of ASSET exist, each having unique capabilities and limitations. This report only addresses version 1.0, which is the version that was delivered to OP-71.

A. THESIS OBJECTIVE

The primary objective of this thesis is to evaluate the maritime patrol aircraft (MPA) detection and allocation models utilized by ASSET, version 1.0. This thesis also proposes a potential long term course of action for evolving ASSET into a comprehensive, flexible, and simple to use tool for top-level ASW appraisals and assessments.

B. OVERVIEW OF ASSET

ASSET was developed in 1990 by Metron, Inc. with the intent of providing CNO (OP-71) with a generic high-level ASW modeling tool. ASSET was designed to aid OP-71 in the development and refinement of ASW top-level warfare requirements (TLWRs) and the ASW Master Plan.

ASSET, Version 1.0, has been designed to operate on a Macintosh II personal computer. It is programmed in Allegro

Common Lisp, an object-oriented programming language, which allows related elements in the simulation to inherit data and functionality via a hierarchical class structure.

The simulated objects in ASSET can be broken into three groups: command, control, and communication (C3) objects; acoustic radiators; and ASW detectors. The C3 objects consist of level 1 commands, level 2 commands, fusion centers, ASWOCs, Submarine Operating Authorities, and communication satellites. Submarines and surface formations are the platforms that radiate acoustic energy. Opposing submarines can be detected by MPA, submarines, fixed area sensors, SURTASS, trip wires, mine fields, HFDF, and sensing satellites. All MPA, submarine, fixed area sensor, and SURTASS detections are made using passive acoustics. No active acoustic or nonacoustic sensors are modeled on these platforms.

ASSET's current measures of effectiveness (MOEs) report on submarine attrition, attrition of MPA by submarines, and the number of surface engagements. A surface engagement is defined as a successful approach to within a user-specified critical range of a surface force by an opposing submarine. ASSET calculates the MOEs by utilizing either an event-step or time-step Monte Carlo simulation.

A more detailed description of ASSET and its capabilities can be found in the ASSET Technical Documentation [Ref. 1].

C. PROPOSAL FOR THE EVOLUTION OF ASSET

1. Design Goals

In order for strategic ASW decision makers to derive maximum benefit from a top-level model, the model should meet three general requirements: flexibility, simplicity, and modeling accuracy. Due to the diversity of ASW schemes and the varied uses of a top-level ASW model, ASSET's foremost requirement should be flexibility. Ideally, ASSET should be able to:

- answer specific as well as generic ASW questions,
- accommodate inexperienced as well as experienced users,
- provide quick answers to limited questions as well as comprehensive answers to large scale questions.

ASSET must be easily understood and simple to use. It should be documented to a level that accommodates an operational type of user, rather than strictly accommodating a trained analyst.

Like most models, ASSET must make the difficult trade-offs between modeling realism and processing speed. These trade-offs must be clearly documented so that the user understands the types of scenarios in which ASSET produces valid and verifiable results, and which types of scenarios may produce less realistic outputs.

2. Potential Follow-on ASSET Tasks

ASSET could be an ideal tool for NPS thesis students to combine their operational and academic experiences in developing ASW models of value to the Navy. Ideally, ASSET should be an easy to use model which allows the user to quickly set up and run a simplified scenario by choosing the platforms and scenarios desired and utilizing default values for non-essential parameters. In this mode of use, ASSET would provide the inexperienced user with quick answers to generic questions. When more detailed, sophisticated, or accurate information is required, the user could select another model that would provide the required level of detail and accuracy. Close coordination with OP-71 could help anticipate potential future modeling requirements such as shallow water, LIC/CALOW scenarios, SSN-21 Seawolf capabilities, or improved acoustic and nonacoustic sensors.

Specific follow-on tasks could include:

- Verify all existing models and the conditions under which they are valid.
- During the NPS conversion to the Common Lisp Object System (CLOS), document the structure of the code and ensure flexibility exists to easily incorporate further models.
- Improve the accuracy or detail of existing models (detection, platform parameters, allocation, tactics, etc.).
- Develop new models for sensors (including active and nonacoustic); platforms (battlegroup ASW, S-3, H-60B, H-60F); and C3 (data fusion, target motion analysis, target trackers).

II. MPA DETECTION MODELS

A. ASSET MPA DETECTION MODEL

1. Overview

The MPA acoustic detection model uses a detection rate scheme to determine whether a detection is made. This model is derived from the passive sonar equation and the random search formula.

ASSET distributes the MPA's sonobuoys uniformly throughout the identified search area. The search area is defined in one of two ways. When an MPA is cued to search a region that has been generated by ASSET's target tracker-correlator, the search area is defined to be the 86% (2σ) containment circle provided by the tracker-correlator. For an uncued MPA search, the search area is a user-defined size, and is randomly located in the user-defined search region.

Only those targets that are located inside the MPA search area at the time the MPA arrives on station are candidates for detection. ASSET assumes that targets that are located outside of the search area at the time that the MPA arrives, stay outside of the search area for the entire duration of the MPA search time. Hence, these targets can never be detected during that MPA mission. Likewise, targets that are located inside the search area when the MPA arrives

are assumed to stay within the search area for the entire duration of the MPA search.

2. Detection Rate Calculation

The key parameter of the random search model is the detection rate. ASSET calculates a detection rate for each target that lies within the search region when the MPA arrives on-station. The detection rate is defined as the ratio of the area searched per unit time over the total area of the search region. A more detailed description of the Random Search Model can be found in Forrest's *Notes on Search, Detection, and Localization Modelling* [Ref 2]. ASSET uses a constant detection rate (γ) given by

$$\gamma = NVW/A_s$$

N = number of sonobuoy channels processed

V = average target speed

W = acoustic sweep width of a single sonobuoy

A_s = search area

The number of sonobuoy channels processed, N, is the minimum of the user-selected number of buoys per search and the user-selected number of buoys that can be processed.

The single buoy acoustic sweep width, W, is calculated as twice the maximum detection range (R_{max}). R_{max} is the maximum range at which the adjusted or actual figure of merit (FOM) is greater than or equal to the propagation loss from the user-entered Proploss Table. Mean FOM is given by

$$FOM = SL - NL + DI - DT.$$

SL = target radiated source level

NL = total noise level (self-noise + ambient noise)

DI = directivity index of the receiver

DT = detection threshold or recognition differential

Actual FOM is obtained by adding an environmental uncertainty correction to the mean FOM. The uncertainty correction is a normally distributed random variable with a mean of zero and a standard deviation of 9 dB. ASSET generates a single uncertainty correction, and thus a single R_{max}, that is used for the entire MPA search period.

SL, NL, DI, and DT are user-entered parameters for the particular MPA-submarine pair.

3. Determination of Detection

After the detection rates are calculated for each submarine that is within the search region at the time the MPA arrives, ASSET sums each of these rates along with the user-entered false alarm rate to obtain a collective contact rate (Γ). The probability distribution for the time to initial contact is an exponential distribution with a rate equal to the collective contact rate. ASSET generates an exponential random number t which represents the time that the MPA detects the real or false target. The exponential random number is obtained from

$$t = -\ln(U\ [0,1]) \ / \ \Gamma$$

where U [0,1] is a uniform random number between zero and one. If t is less than or equal to the total time that the MPA is on-station, a detection is reported at time t.

To determine which target in the search region is detected, ASSET stacks the detection and false alarm rates end to end as shown in Figure 1. ASSET then draws another uniform random number, this one on the interval [0,Γ], to determine which submarine (or false alarm) will be reported as the contact. ASSET only allows one detection (real or false) per MPA mission.

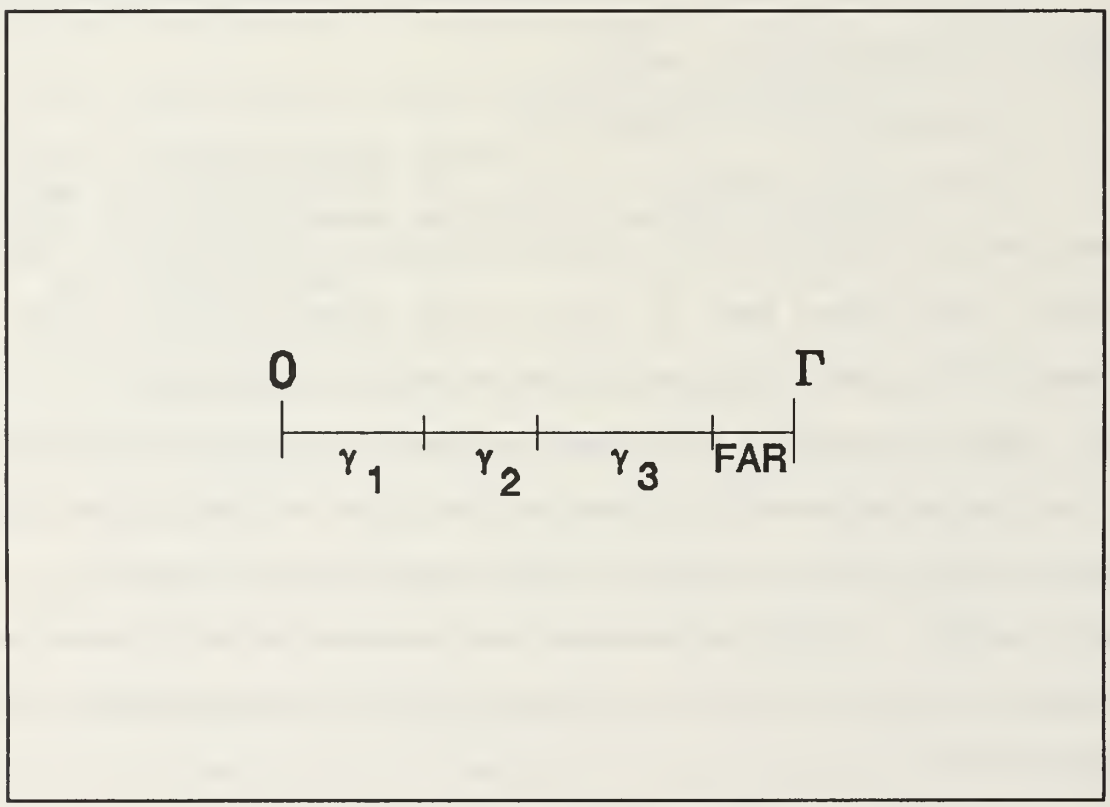

Figure 1. Stacking of Detection and False Alarm Rates

4. Model Verification

A simple MPA verses submarine scenario was constructed to verify that the ASSET Monte Carlo simulation will produce results consistent with the analytic formulas on which it is based. Random search, on which ASSET is based, predicts that the cumulative probability of detection by time t (CDP(t)) is

$$CDP(t) = 1-\exp(-\gamma t),$$

where γ is the detection rate.

The scenario, as depicted in Figure 2, involves a Red submarine patrolling in a box with area A_t in the Greenland / Iceland gap. A single Blue MPA is sent out (uncued) to search the patrol area. Figure 2 depicts this search region as a circle. Since ASSET assigns the center of the search area randomly within the search region (A_t), 50,000 nm^2 was selected as the user-defined uncued search area (A_s). This ensures that the target will always be within the search area at the time the MPA arrives on-station.

The following parameters were selected to provide a detection rate (NVW/A_s) equal to 0.064 hr^{-1}:

N = 16 (sonobuoys processed),

V = 10 kts (target speed),

W = 20 nm (sweep width of a single sonobuoy),

A_s = 50,000 nm^2 (uncued search area).

With a detection rate of 0.064 hr^{-1} and a search time of 10 hours, CDP is calculated to be 0.473. The scenario was

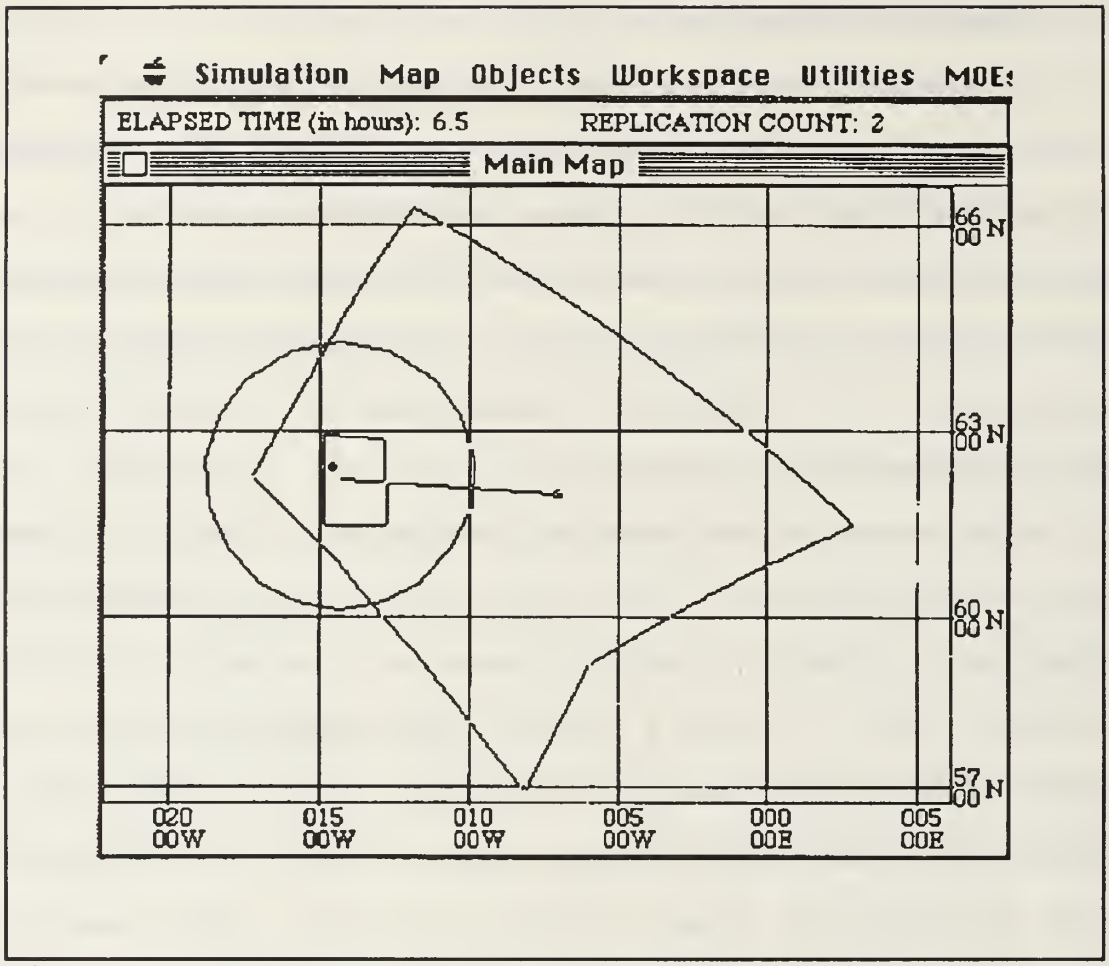

Figure 2. Model Verification Scenario

run for 1000 replications, and a CDP of 0.45 was obtained. The 95% confidence interval for the result of this simulation is given by

$$\hat{p} \pm 1.96\sqrt{\hat{p}\hat{q}/n},$$

$$= .45 \pm 1.96\sqrt{(.45)(.55)/1000},$$

$$= .45 \pm .03,$$

where $\hat{p}$ is the estimator for CDP, $\hat{q} = 1 - \hat{p}$, and n is the number of replications. The analytical CDP of 0.473 falls

within this interval, so the simulation results are judged to be consistent with theory.

5. Critique of Model

a. Deviations from the Random Search Model

The ASSET detection model follows the random search model for the situations when the target is restricted from crossing the search region boundary during the time of search. This restriction can be realized by a physical scenario when the target's motion is confined to a patrol area, and this patrol area is either totally contained within or mutually exclusive of the search region. Figure 3 depicts the three possible combinations for the intersection of MPA search and target patrol regions. The ASSET detection rate is most appropriate for the scenario depicted in Figure 3a. If either of the other two scenarios is desired, the current ASSET MPA detection model may not be as useful.

The current ASSET model follows the random search model without restrictions when the target is stationary, and it provides a good approximation for slow moving targets (i.e., targets with a small likelihood of crossing the search region boundary). But due to the duration of an MPA search and the potential speed of the targets, a detection rate which allows targets to cross the search area boundary may be more appropriate. This new detection rate would be calculated by multiplying the existing detection rate by the expected

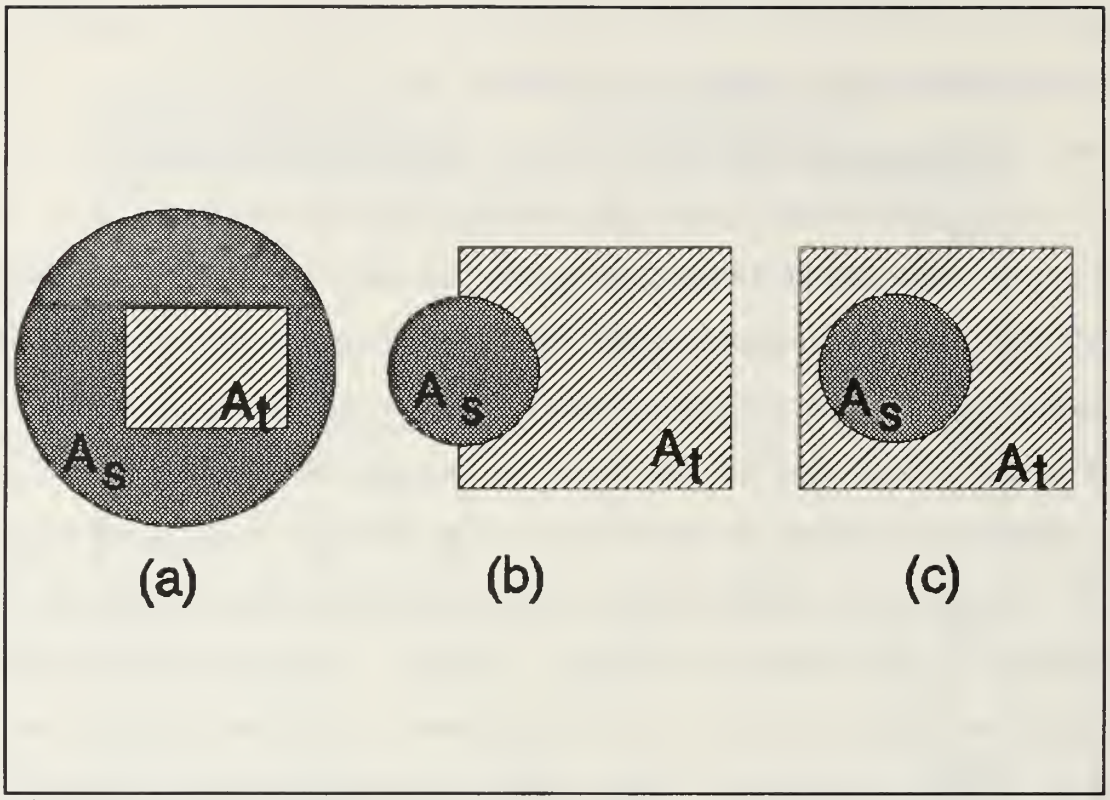

Figure 3. The Three Possible Geometries of Intersecting Regions: (a) A_t Totally Contained in A_s, (b) A_s Partially Overlapping A_t, (c) A_s Totally Contained in A_t.

fraction of the search time that the target is in the search region. This model assumes that each target will spend the fraction (A_{st}/A_t) of time in the search area.

For a patrolling target, the modified detection rate is given by

$$\gamma = (NVW/As)(A_{st}/A_t)$$

where A_{st} is the area of the intersection of the MPA search region and the target patrol area, and A_t is the target patrol area. This detection rate accounts for the general case of a patrol area that can be located anywhere relative to the MPA search region and covers all three scenarios depicted in

Figure 3, hence removing a possible modelling restriction of the current ASSET model.

The new model assumes "complete mixing" of the target throughout A_t. That is, the target spends the fraction A_{st}/A_t of its time in A_s and is available for detection for that specific period of time. The current ASSET model assumes "complete segregation" in that targets starting outside A_s remain outside for the entire search period, and targets starting inside remain inside. A better model would probably give results somewhere between these two, but such an analytic model is not currently available. Neither analytic model is accurate in all situations. If computer processing time allows, a better solution might be to use the simulation-generated target track to determine whether or not a detection has occurred. Two such models are presented in Sections B.1 and B.2 (pp. 17-31).

Note that for a transitting target, the target patrol area (A_t) has no obvious meaning. But for a transitting target, ASSET's assumption that the target will neither enter nor exit the search region for the duration of the search time also becomes less likely.

b. Inaccurate Results Caused by Unrelated Parameters

During the first several attempts to verify the MPA detection model, grossly inaccurate results were obtained. After extensive trouble shooting, it was determined that the

inaccuracies were caused by two unrelated parameters of the simulation.

The first unrelated parameter that had a devastating effect on the ability of the MPA to attack a submarine was the submarine's counter-kill capability against the MPA. The default value for the counter-kill capability is 'NIL', meaning that the submarine has no counter-kill capability against an MPA. When this default value is left unaltered, the ASSET software will not permit the MPA to attack any submarines. Hence until a value is entered for the counter-kill parameter, the MPA will be unable to successfully attack an enemy submarine regardless of the other parameters involved. This deficiency appears to be easily correctable by either changing the default value for the counter-kill capability to zero or by altering the Lisp statement that prohibits an attack when the counter-kill variable is 'NIL'.

The second unsuspected parameter that significantly affected the ability of the MPA to detect and kill a target was the submarine's false alarm rate. For the period of time that a submarine is engaged in resolving its own false alarms, it is undetectable by other platforms. Apparently due to the large amount of time that a submarine takes to resolve a false alarm, even extremely small submarine false alarm rates significantly reduce the detectability of the submarine. Using the default value of 0.9 false alarms per day, the CDP for 100 replications of an optimistic scenario was reduced

from 1.0 down to 0.78. Using the value of one false alarm per hour reduced the CDP for 100 replications of this same scenario from 1.0 down to 0.08.

c. Uniform Distribution of Sonobuoys

The hard-wired placement of sonobuoys uniformly throughout the circular search region negates the advantages in detection capability obtained through the use of tactics by the MPA. Without employing different sonobuoy patterns, a model cannot adequately reflect the MPA's ability to perform many of its missions such as: choke point interdiction, area sanitation, and convergence zone (CZ) investigation. The uniform buoy positioning also negates the ability of an MPA to increase its coverage area by sanitizing an area and laying another buoy pattern at a different location within the search region.

ASSET uses the search probability area (SPA) from the tracker-correlator to define the search region for a cued MPA search. Hence, this search region represents a bivariate normal distribution of the tracker's target position. For large SPAs, the uniform distribution of sonobuoys throughout the search region will inadequately reflect the MPA's ability to expend most of its search effort towards the center of the SPA (where the target is most likely to be located).

d. Pattern Sweep Rate

ASSET's calculation for the MPA sweep rate (NVW) assumes that a sensor has continuous detection out to the maximum detection range, even when CZ detections exist. The sweep rate also assumes that the buoy spacing is greater than or equal to the individual buoy sweep width. Because buoys are typically dropped with smaller buoy spacings, these assumptions could significantly exaggerate the pattern sweep rate, especially in convergence zone conditions.

e. Single Contact per Mission

ASSET only permits a single contact per MPA mission, even if that contact is a false alarm and the MPA has sufficient time remaining on-station. After the MPA completes its one engagement, no further search is conducted. It seems reasonable that another exponential random number should be drawn to determine the time to the next contact. Allowing successive searches when time permits will more closely represent an MPA's actions.

f. Confidence of Contact Reports

If a real or false detection is achieved, a contact report containing the estimated position and velocity of the target is generated. This report is sent before the MPA determines whether the target will be successfully prosecuted. If hostilities have not yet begun, ASSET does not attempt any further action (i.e. tracking) by the MPA. If hostilities

have started, ASSET will draw an exponential random number with a user-input mean prosecution time. If the random number is less than the remaining time on-station, the prosecution is successful.

To more closely represent the ability of an MPA to gain confidence in a detection as time progresses, ASSET should attempt a prosecution if a contact is made during the prehostilities phase. To communicate this gained confidence, ASSET should send another contact report if a successful prehostility or posthostility prosecution has occurred.

B. ALTERNATE DETECTION MODELS

In an attempt to best meet the modeling design goals as outlined in Section C.1, two potential MPA detection models are proposed. The main difference between these models and the ASSET MPA model is that they explicitly model the area covered by the actual sonobuoy patterns instead of uniformly distributing the sonobuoys throughout a search region. Therefore, the model can determine whether the simulated submarine tracks enter into detection range of the sonobuoy pattern. Both of the proposed models may require more processing time to determine detections, but in turn each should provide more realistic results.

1. Rectangular Pattern Approximation Model

The Rectangular Pattern Approximation Model (RPAM) determines the area of ocean that a specific sonobuoy pattern

can cover and models the shape and size of this area with a rectangle. Whenever an enemy submarine enters this coverage area, the MPA will detect it with a user-entered probability of detection (P_d).

a. Determination of Pattern Coverage Area

The dimensions of the rectangle representing the pattern coverage area will be calculated based on the user-entered pattern type and the mean detection range (MDR). MDR is defined as the maximum range (R_{max}) which gives a P_d of 0.5 (FOM'=TL) and is obtained from the user-entered Proploss Table. The rectangular coverage area for the 565 direct path default pattern is shown in Figure 4. Since each target may have a different R_{max}, a separate pattern coverage area will be computed for each pattern/target pair.

The spacing between buoys will be based on 1.5 times the MDR when CZ detections are not predicted and 1.5 times the width of the CZ annulus (CZW) when CZ detections are predicted. Figure 5 shows the extent of CZ coverage at this spacing. R_{max} and CZW will be computed, as ASSET currently does, by matching the user-entered Proploss Table with the passive sonar figure of merit equation (FOM = SL - NL + DI - DT). The FOM will still be adjusted to include the normally distributed (mean of zero, standard deviation of nine) environmental uncertainty correction. The target (SL), environmental (NL), and system (DI, DT) parameters will be

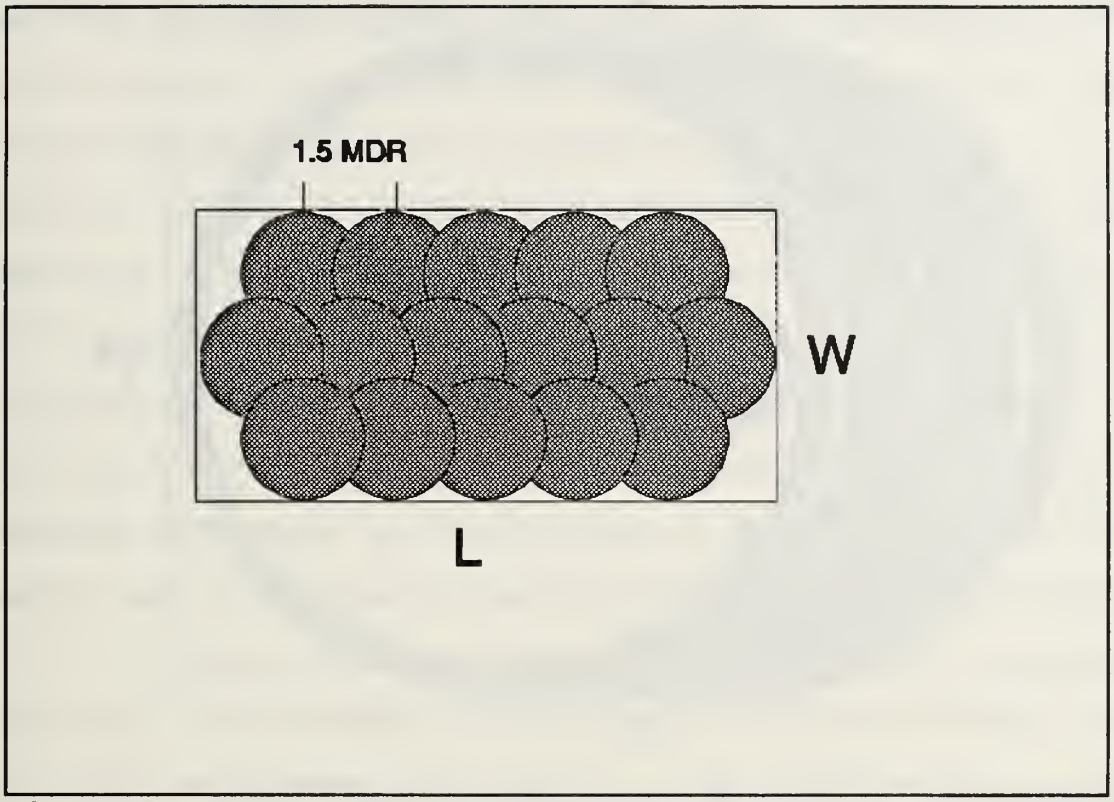

Figure 4. Pattern Coverage Area for Direct Path Detections

obtained as previously discussed.

When the passive sonar equation predicts that CZ detections are not obtainable, the length (L) and width (W) of the pattern are given by

$$L = [1.5(n-1)+2]R_{max},$$
$$W = [1.5(m-1)+2]R_{max},$$

where n is the maximum number of buoys in a single row, and m is the number of rows in the chosen pattern. When CZ detections are predicted, L and W are given by

$$L = 1.5(n-1)CZW+2R_{max},$$
$$W = 1.5(m-1)CZW+2R_{max}.$$

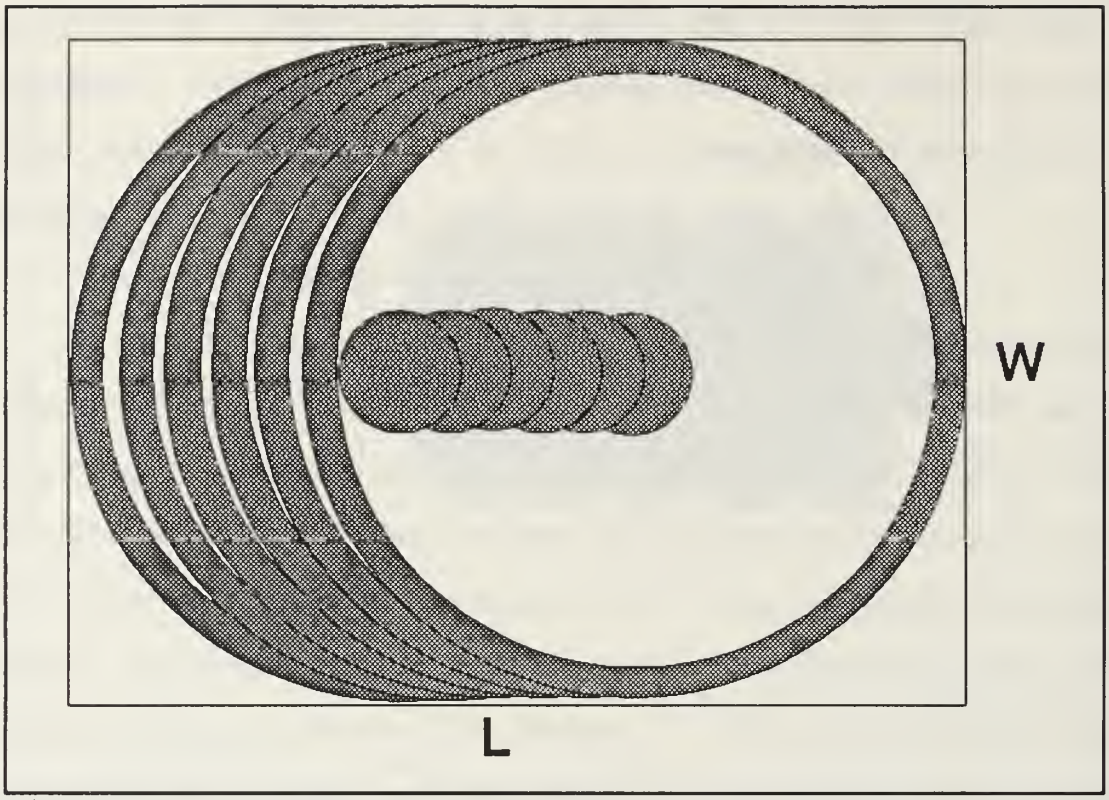

Figure 5. Extent of Pattern Coverage Area for CZ Detections

For a cued search, the center of the search region rectangle will be geographically placed at the tracker-correlator's best estimate of target position at the midpoint of the MPA search. Otherwise, the center will be randomly placed within the user-entered uncued search region.

Figure A1 in the Appendix depicts a flowchart for determining the RPAM coverage area.

b. Determination of Detection

Since the actual size and shape of the sonobuoy coverage area is known, an analytic solution is no longer necessary. The simulation can be used to determine detection.

Whenever a target enters the rectangle representing the coverage area, it will be detected at a user-entered P_d by using a random number draw. A detection opportunity will not occur if the MPA is engaged with another target (localizing, tracking, or attacking), or is in the process of resolving a false contact. The calculation to determine whether the target enters the rectangle involves finding whether any of the target track segments intersect any of the four segments that make up the perimeter of the rectangle, or whether any track segment lies entirely within the rectangle.

Three flowcharts depicting the RPAM detection algorithm can be found in the Appendix, Figures A2, A3, and A4. The two shadowed boxes on Figure A2 indicate the existence of optional sub-levels to the algorithm.

To reduce computation time, the initial step in determining detection opportunities should be to identify and eliminate from further consideration those targets that cannot possibly be detected during the MPA's search time. This can be accomplished by disregarding each target whose present range exceeds the maximum distance that it could travel during the search period. Next, convert the center of the pattern coverage area and the end points of each remaining track segment to cartesian (X-Y) coordinates. The origin of the coordinate system will be at the pattern center with the X-axis parallel to the rows of buoys. The routines for lat/lon

to X-Y conversion and bearing/range between two points already exist in ASSET. Next, disregard all track segments whose end points both lie on one side of the rectangle (i.e., x coordinate of both end points > L/2), since none of these could possibly enter the coverage area. Check whether any of the remaining target track end points lie inside the rectangle. If any end point lies within the rectangle, a detection opportunity will be scheduled for the time that the target enters the rectangle. Once a detection opportunity is found, no more checks need to be conducted on that target.

If any target tracks still remain unresolved, compute the intersection of each line with three of the rectangle sides. Computing the fourth side would be redundant. The point of intersection is found by first calculating the equations for the lines that contain the respective segments and solving for their intersections. The final step involves determining whether the X or Y coordinate of the intercept point lies between the two sides of the rectangle.

c. Effect of False contacts

As in ASSET, false contacts are generated by a Poisson process with a user-entered false contact rate. An exponentially distributed random number will be drawn to determine the time of the false contact. For simplicity, the time to investigate a false contact will be modelled

identically to the time to localize a real contact. As with detections, a false contact will not be processed if the MPA is engaged at the time of the false alert.

2. Glimpse Rate Model

All of the continuous detection sensors in ASSET except the MPA utilize a glimpse rate to determine detection opportunities. A MPA Glimpse Rate Model (MGRM) would approximate a continuous-looking sensor pattern that has a P_d of less than 1.0 with a glimpsing sensor region that has a P_d of 1.0 (as ASSET currently does with the tripwire sensor). The sensor region would then be glimpsed to provide a detection rate identical to that obtained by a continuous sensor conducting random search.

Detections for MGRM are based on the random search model where the detection rate is defined as the ratio of the relative area searched per unit time over the total area of the search region. Random search predicts that a target, moving randomly through a field of continuous stationary sensors, will be detected at a certain rate. By glimpsing the sensor field at this detection rate, MGRM can produce an identical detection rate regardless of how the target is moving.

For a cued search, the center of the search region rectangle will be geographically placed at the tracker-correlator's best estimate of target position at the midpoint

of the MPA search. Otherwise, the center will be randomly placed within the user-entered uncued search region.

a. Area of the Search Region

The area of the search region for MGRM is similar to the pattern coverage area used by RPAM as described in Chapter II, Section B.1.a. MGRM uses one MPA search region against all targets. As shown in Figure 6, the search region is defined as the rectangle that contains the expected coverage area of the user-selected sonobuoy pattern. In other words, the sonobuoy pattern is laid based on a spacing of 1.5 times the mean detection range which is predicted against the source level of the target that generated the cue, and the search region is the expected area covered by this pattern.

For a cued search, MGRM uses the estimated target source level (SL_0), provided by the most recent update to the tracker, to determine FOM_0 and hence the dimensions of the search region. Uncued search will use a default value for SL_0. Mean FOM_0' and actual FOM_0 are calculated as before:

$$FOM_0' = SL_0 - NL + DI - DT,$$
$$FOM_0 = FOM_0' + X,$$

where X is a normally distributed random variable with a mean of zero and a standard deviation of nine. The maximum range, R_{0max}, is determined from the user-entered Proploss Table as before, and the dimensions of the search region for non-CZ detections are given by

$$L_0 = [1.5(n-1)+2]R_{0max},$$

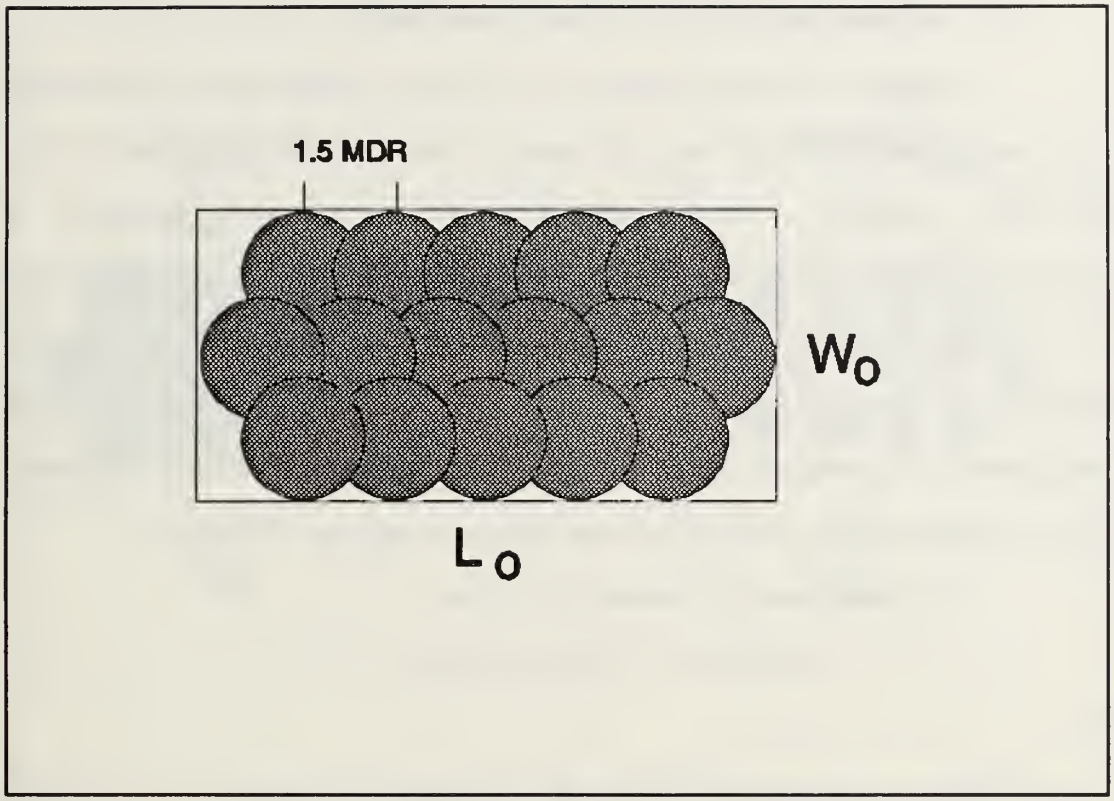

Figure 6. Pattern Coverage Area for Direct Path Detections

$$W_0 = [1.5(m-1)+2]R_{0max}.$$

where n is the maximum number of buoys in a single row and m is the number of rows in the sonobuoy pattern. For CZ detections the buoy spacing is based on the width of the CZ annulus (CZW) and the dimensions of the search region are given by

$$L_0 = 1.5(n-1)CZW_0+2R_{0max},$$
$$W_0 = 1.5(m-1)CZW_0+2R_{0max}.$$

Figure A5 in the Appendix depicts a flowchart for determining the MGRM coverage area.

b. Determination of Detection Rate

When an MPA arrives on-station, MGRM will calculate a glimpse rate and initial glimpse time for each potentially detectable target. As in ASSET's other glimpse models, a target is deemed potentially detectable if its range from the MPA is less than its maximum speed multiplied by the MPA search time. The initial glimpse time will be determined from an exponential random draw using the inverse of the glimpse rate (or detection rate) as the mean glimpse interval.

Random search predicts that

$$CDP = 1 - \exp[-CR(t)],$$

where

$CR(t)$ = coverage ratio by time t,

$$= \frac{\text{area covered by time t assuming no overlap}}{\text{total area to be searched}},$$

$$= \frac{V_i w t + A_i}{A_0}.$$

V_i = target velocity

w = pattern sweep width (or length of rectangle, L_i)

A_i = initial area covered by the pattern

A_0 = area of the search region (L_0 x W_0)

As illustrated in Figure 7, the initial area covered by the pattern is the minimum of L_i X W_i and $2N\pi R_{imax}^2$ where N is the total number of buoys in the pattern.

The mean time to detect (MTTD) is

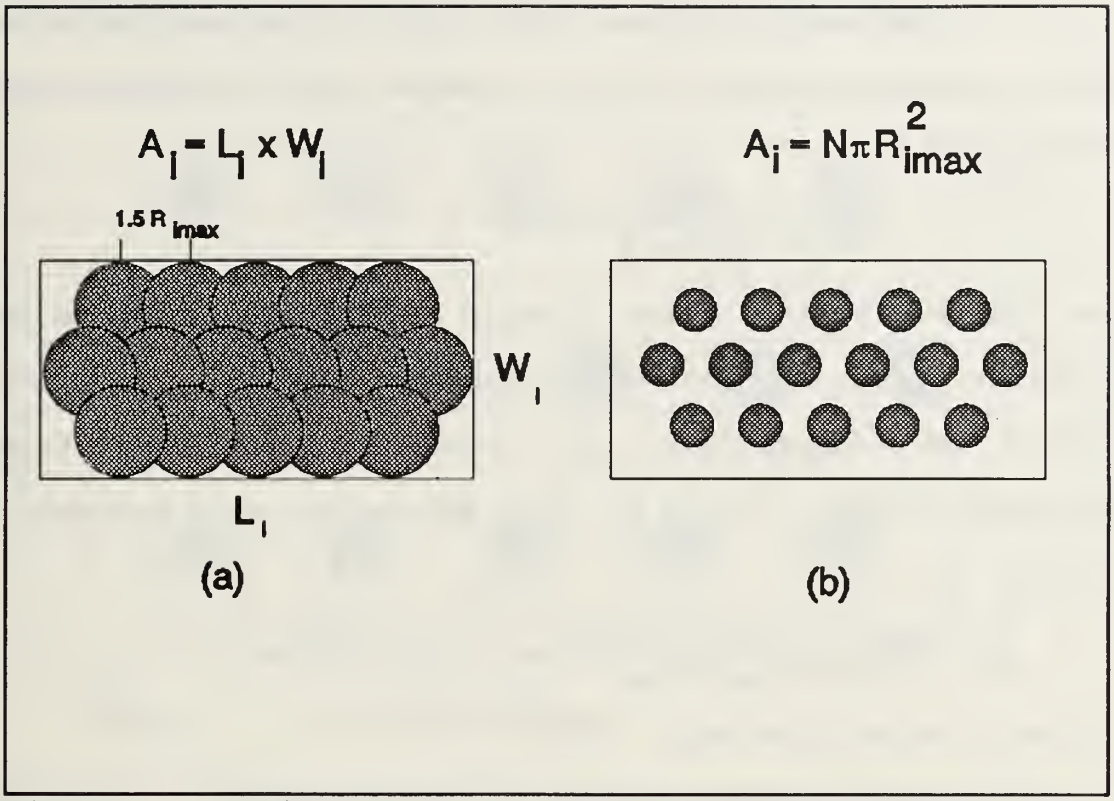

Figure 7. Initial Areas Covered by Pattern When Buoy Coverage Areas (a) Overlap and (b) Don't Overlap

$$\begin{aligned} MTTD &= \int_0^\infty \exp[-CR(t)]\, dt, \\ &= \int_0^\infty \exp[-(V_i w t + A_i)/A_0]\, dt, \\ &= \int_0^\infty \exp(-V_i w t/A_0) \exp(-A_i/A_0)\, dt, \\ &= (A_0/V_i w)\ \exp(-A_i/A_0). \end{aligned}$$

A constant detection rate which provides the same mean time to initial detection can be obtained from the reciprocal of the MTTD, and can be expressed as

$$\gamma = (V_i w/A_0)\exp(A_i/A_0).$$

The length (L_i) and width (W_i) of the coverage area are calculated as before from the passive sonar equation with an FOM_i given by

$$FOM_i' = SL_i - NL + DI - DT,$$
$$FOM_i = FOM_i' + X.$$

Since the only variable that changes between FOM_0 and FOM_i is the source level, FOM_i can be more quickly calculated from the equation $FOM_i = FOM_0 + SL_0 - SL_i$. R_{imax} is once again obtained from the Proploss Table. L_i and W_i, which define the area searched, are given by

$$L_i = \min\{[1.5(n-1)R_{0max} + 2R_{imax}], [(2n-1)2R_{imax}]\},$$
$$W_i = 1.5(m-1)R_{0max} + 2R_{imax},$$

for non-CZ detections and

$$L_i = \min\{[1.5(n-1)CZW_0 + 2R_{imax}], [(2n-1)2R_{imax}]\},$$
$$W_i = 1.5(m-1)R_{0max} + 2R_{imax},$$

for CZ detections.

When more than one row of sonobuoys is used in a pattern, the positions are offset. Therefore for small detection ranges relative to the buoy spacing, Figure 8 shows that two rows will contribute to the sweep width (L_i) of the pattern. If a pattern is chosen that only contains one row, the first term of the L_i equation must be used ($1.5[n-1]R_{0max} + 2R_{imax}$).

A flowchart depicting the MGRM detection (glimpse) rate algorithm can be found in the Appendix, Figure A6.

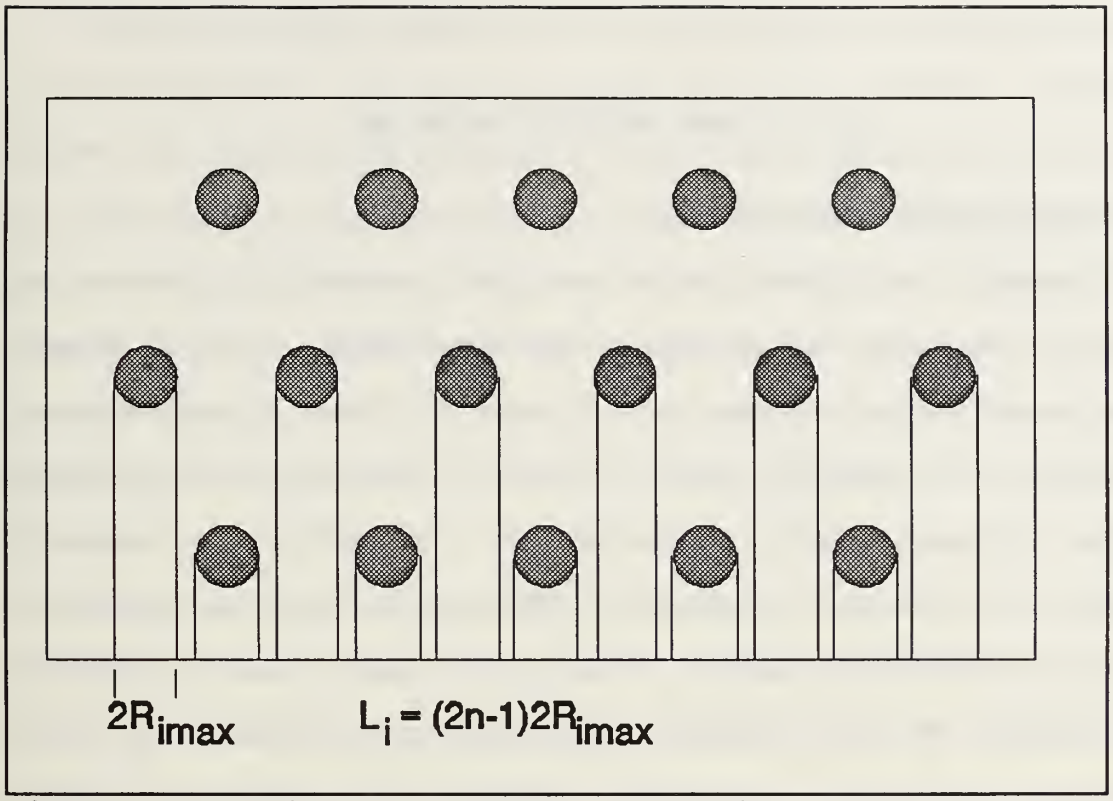

Figure 8. Equivalent Pattern Sweep Width When $R_{imax} \leq$ 1/4 Buoy Spacing

c. Effect of False Contacts

As in ASSET, false contacts are generated by a Poisson process with a user-entered false contact rate. An exponentially distributed random number will be drawn to determine the time of the false contact. For simplicity, the time to investigate a false contact will be modelled identically to the time to localize a real contact. As with detections, a false contact will not be processed if the MPA is engaged at the time of the false alert.

III. MPA ALLOCATION MODEL

A. ASSET MODEL DESCRIPTION

In ASSET each ASWOC has a specific non-overlapping ocean area and a number of assigned MPA squadrons, both of these being user-defined. Based upon tracker-correlator information obtained from the ASW fusion center, ASWOCs cue their MPA assets to investigate areas which are likely to contain targets of interest. Remaining MPA may also be assigned to perform uncued area search. ASWOCs only make their MPA search assignments at user-selected allocation intervals. At each allocation interval, the fusion center will provide the ASWOC with an 86% (2σ) SPA for each suspected target within the ASWOC's ocean area.

ASSET constructs a table that matches each available MPA with each SPA within the ASWOC's operating area. Available MPA include all MPA on the ground in a ready status, as well as those MPA conducting uncued search that have not yet reported a detection. ASSET performs three calculations for each SPA/MPA match up and enters them in the table. The calculations are: 1) projected SPA size at the midpoint of the MPA search, 2) amount of time on-station available for search, and 3) transit time to the SPA.

From this table, ASSET first eliminates each SPA/MPA pair whose projected SPA size exceeds a user-entered maximum. ASSET also eliminates each pair whose computed time on-station is less than a user-entered minimum (uncued, divertable MPA may have a different user-entered minimum). From the remaining pairs, ASSET myopically selects SPA/MPA combinations using minimum transit time as the selection criterion. This pairing continues until either all of the SPAs or all of the MPA have been exhausted. If any available MPA remain, up to a user-entered maximum will be assigned to search a user-selected uncued region. The MPA's search region is randomly located inside this designated uncued area search region.

B. POTENTIAL AREAS FOR IMPROVEMENT

1. Criterion for SPA/MPA Matching

The parameter that typically best summarizes the effectiveness of an MPA search is probability of detection. Therefore the ASWOCs should allocate their MPA to optimize this parameter. ASSET's current scheme for prioritizing SPA/MPA pairs can actually be counterproductive.

In *Search and Detection* [Ref 3], Washburn discusses three models for optimizing search effort when searching a bivariate normal target distribution. Each model demonstrates that CDP increases as $Vwt/4\pi\sigma^2$ increases, where w is sensor sweep width, t is the duration of search time, and $4\pi\sigma^2$ represents the area of the tracker's 2σ bivariate normal SPA.

Hence, the CDP can be optimized by optimizing the expression $Vwt/4\pi\sigma^2$. If calculating sweep width for each potential MPA/SPA pair proves to be too processor intensive, a nearly optimal allocation can be obtained by matching MPA/SPA pairs to maximize $Vt/4\pi\sigma^2$.

2. Relieving Active Contacts

Currently ASSET only allocates MPA at the predetermined allocation intervals. If an MPA is tracking a target during prehostilities or attacking during hostilities, a relief MPA should be sent out to arrive on-station at the time that the initial MPA must depart the search region. This will significantly increase the probability of successfully maintaining track on a target over extended periods of time. It will also increase the probability of achieving a kill once a target is detected.

To include the relief concept in the event step simulation, schedule an event to launch a relief MPA (if available) whenever a contact report is generated. If the current simulation time is greater than the MPA off-station time minus the transit time, the relief MPA will be launched at the current time. Otherwise, the event will be scheduled for the MPA off-station time minus the transit time.

3. Multiple MPA per SPA

Currently ASSET only permits one MPA to search a SPA per allocation interval. If only a few large SPAs exist in an

ASWOC's operating area, it would be more advantageous to assign more than one MPA to search regions within a SPA.

IV. SUMMARY

The primary objective of this thesis is to analyze and recommend improvements to the Maritime Patrol Aircraft (MPA) detection and allocation models utilized by the ASW Systems Evaluation Tool (ASSET). ASSET is a generic high-level ASW modeling tool, designed to aid OP-71 in the development and refinement of ASW top-level warfare requirements and the ASW Master Plan. ASSET's strengths lie in its in-depth C^3I and logistics modeling of submarine, MPA, and overhead surveillance in large scale ASW campaigns.

A. MPA DETECTION

To reduce the processing time required by ASSET, Metron made simplifications to the MPA detection model which limit its ability to effectively simulate some MPA tactical ASW scenarios. ASSET's MPA model forces sonobuoys to be uniformly placed throughout the search region, negating the advantages in detection capability obtained through the use of tactics. The model also does not capture movement of the target into or out of the search region during the search period.

This thesis proposes two MPA detection models which overcome some of the limitations of the ASSET MPA model. Both proposed models utilize a user-selected sonobuoy pattern and model the actual locations of the buoys within the field.

The first model proposed, the Rectangular Pattern Approximation Model (RPAM), determines whether the actual track of a target enters the region covered by a user-selected pattern during the period that the MPA is searching. Targets entering the pattern coverage area will be detected with a user-selected probability of detection.

The second model, the MPA Glimpse Rate Model (MGRM), replaces the continuous sonobouy sensor field which has a P_d of less than 1.0 with a discontinuous (glimpsing) sensor region. The glimpsing sensor field will detect a target which is within the sensor region at the time of a glimpse with a P_d of 1.0.

MGRM should provide more realistic results than either the ASSET MPA detection model or RPAM, but large detection rates may be achieved against fast or noisy targets.

B. MPA ALLOCATION

ASSET allocates MPA to cues generated from the tracker-correlator by myopically selecting SPA/MPA combinations using minimum transit time to the SPA as the selection criterion. Using a selection criterion which maximizes the sensor sweep rate (Vw) divided by the SPA size should increase cumulative detection probability with very little increase in the processing time to perform an allocation. When an MPA is tracking a target during prehostilities or attacking during hostilities, a relief MPA should be sent out to arrive on-

station at the time that the original MPA must depart the search region. Once a target is detected, this change will significantly and more realistically increase the probability of killing or successfully maintaining contact on a target over an extended period of time.

APPENDIX

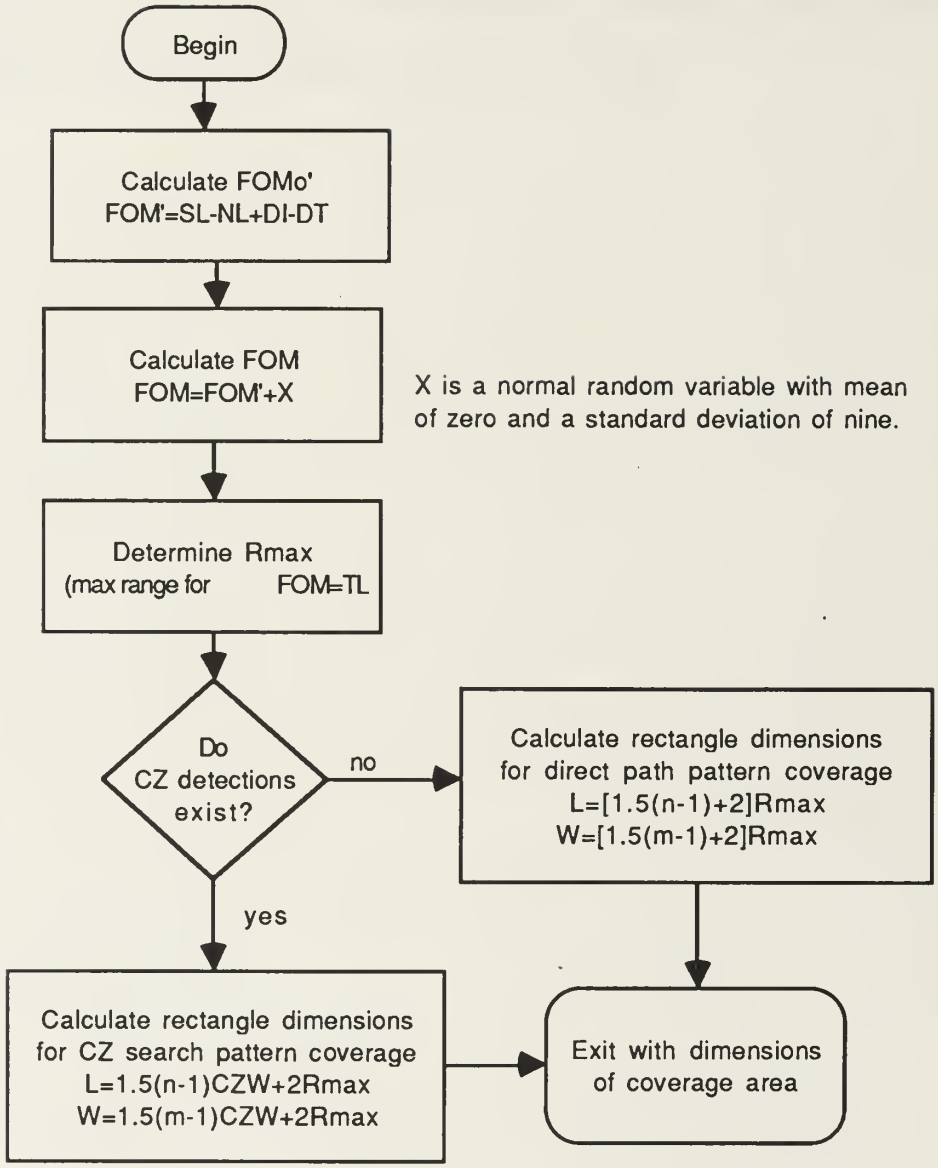

Figure A1. RPAM Detection Coverage Area Algorithm

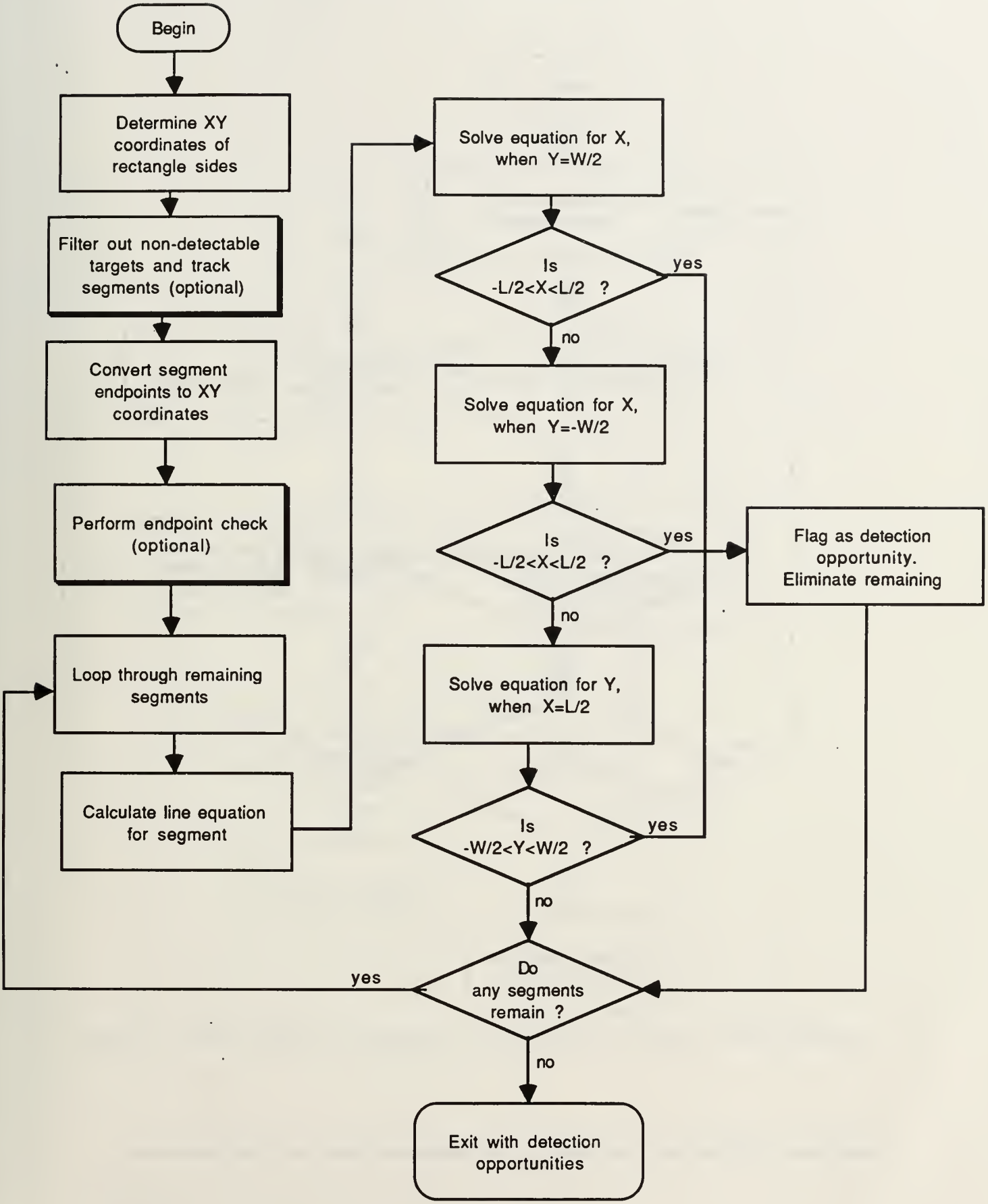

Figure A2. RPAM Detection Algorithm

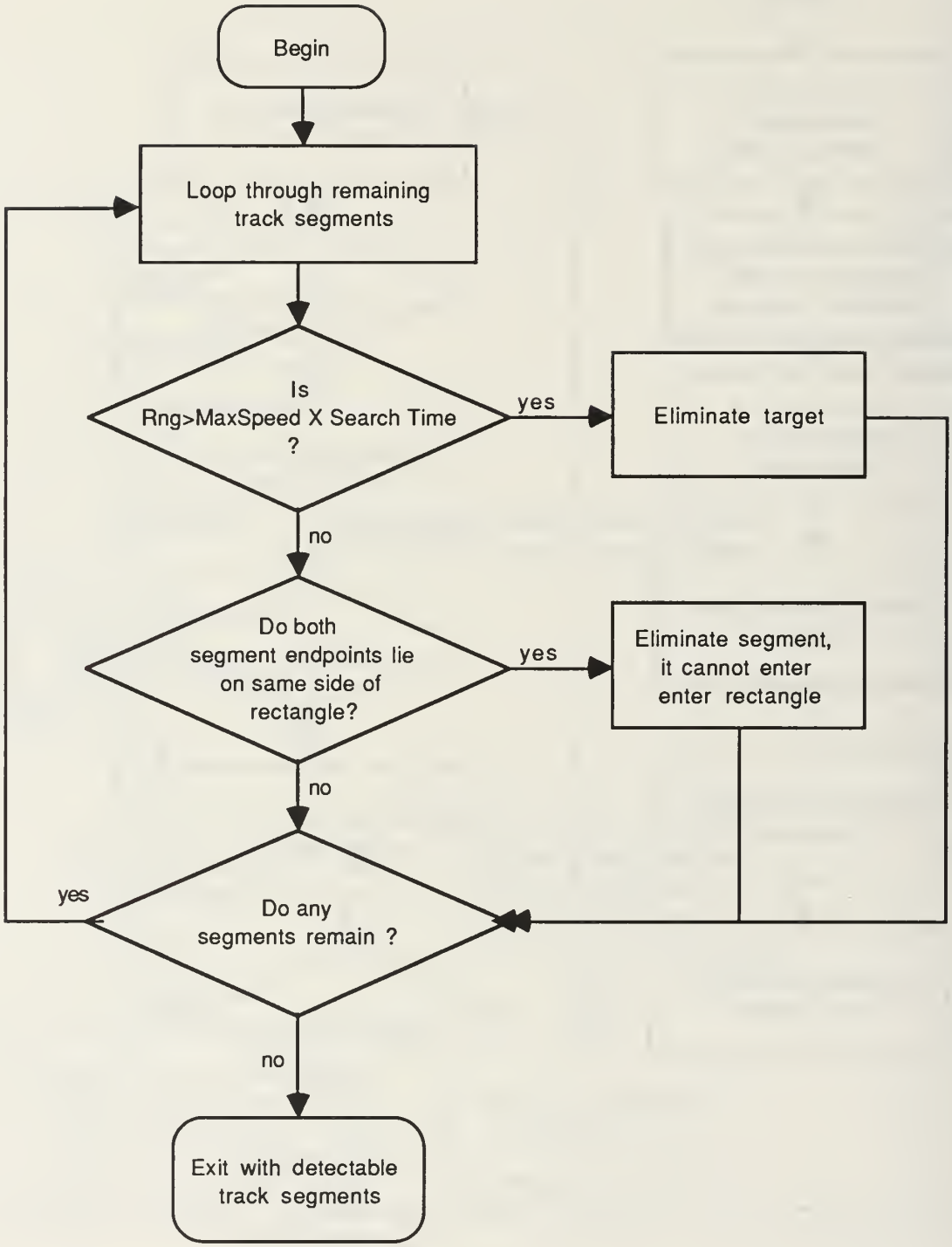

Figure A3. RPAM Algorithm for Identifying Non-detectable Targets and Track Segments

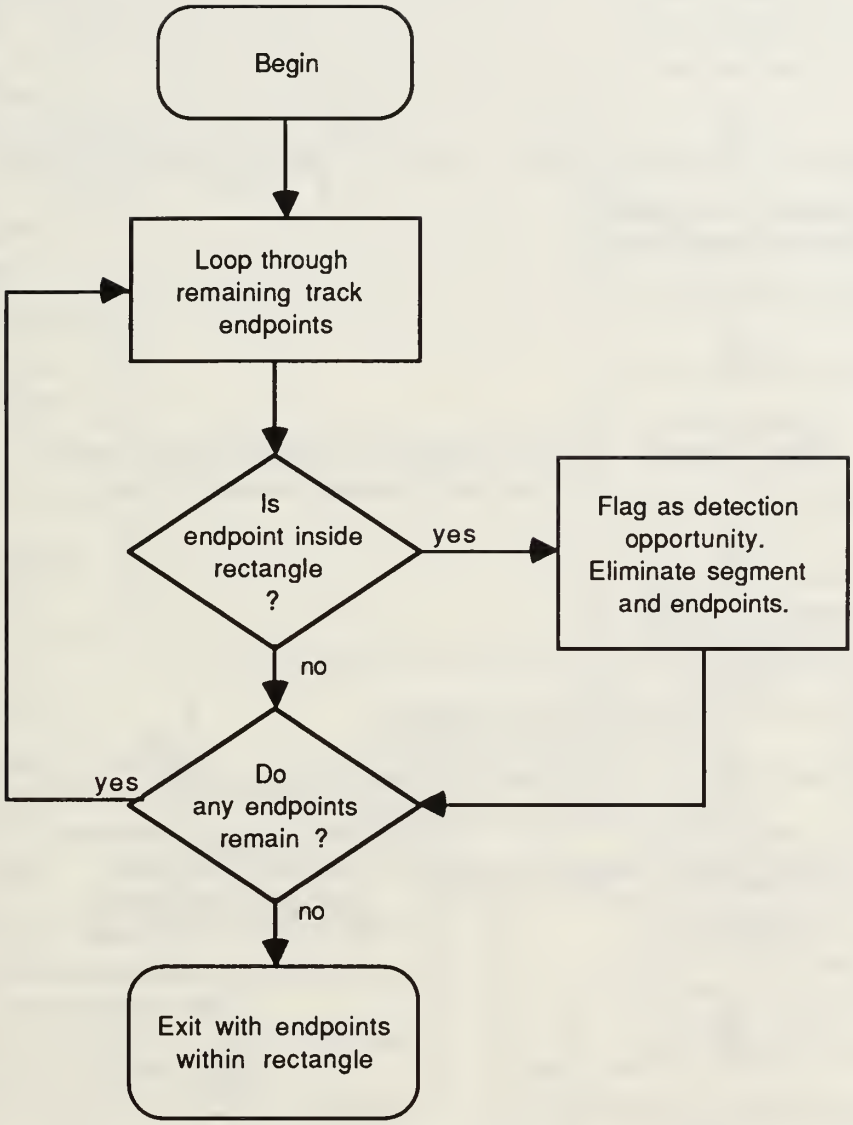

Figure A4. RPAM Algorithm for Determining if Track Segment Endpoints Lie Within Rectangle

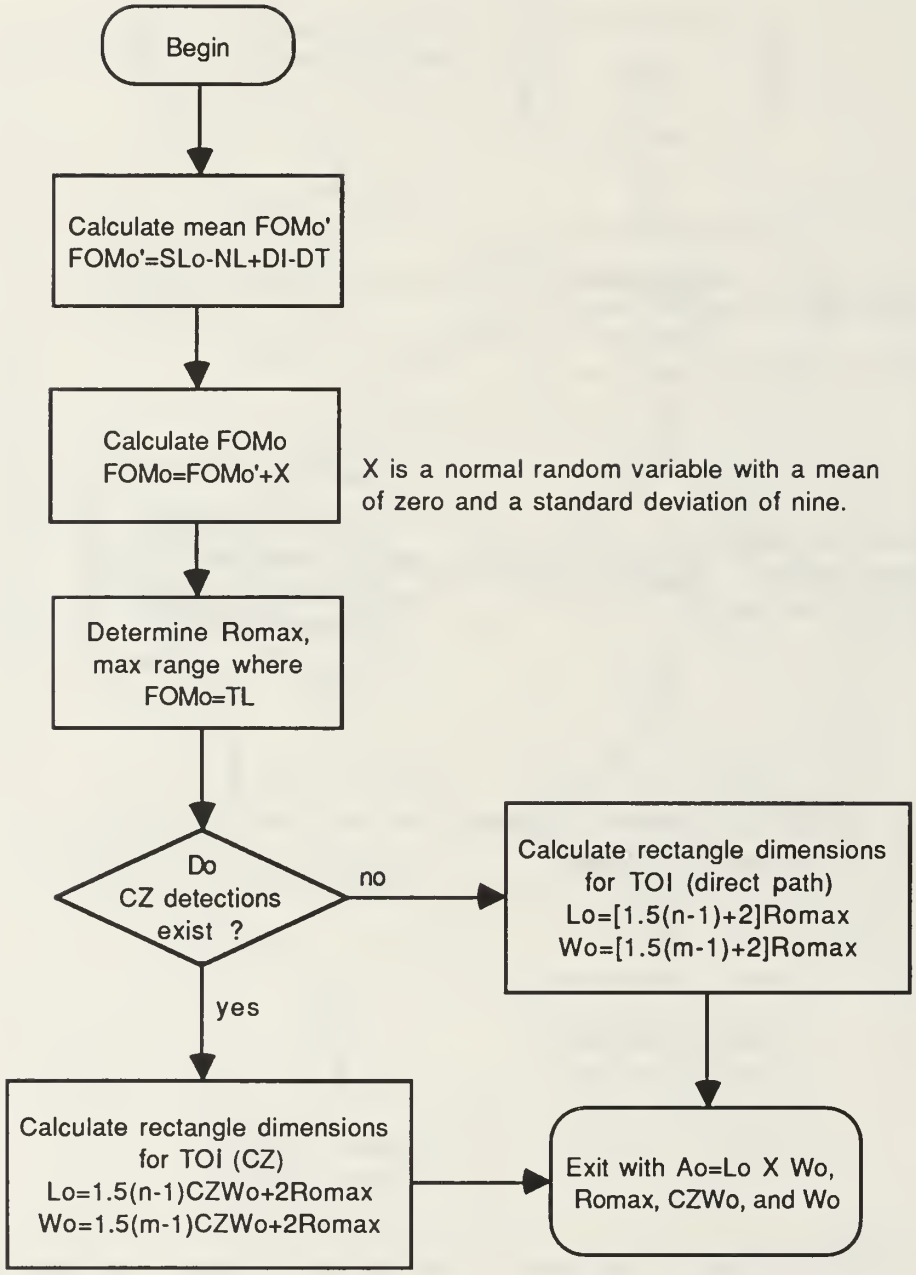

Figure A5. MGRM Search Area Algorithm

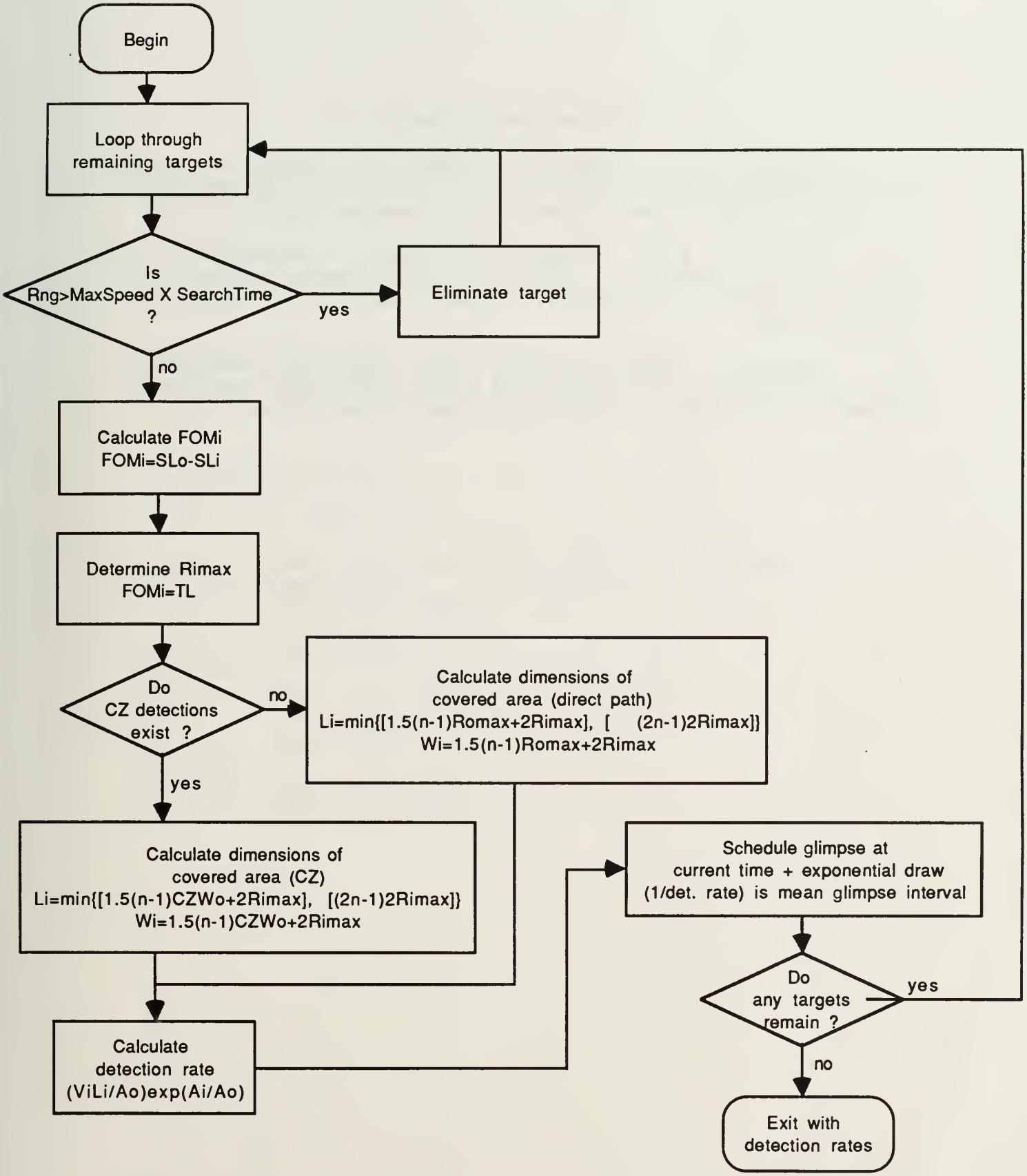

Figure A6. MGRM Detection (Glimpse) Rate Algorithm

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3. Washburn, A.R., *Search and Detection*, Military Applications Section, Operations Research Society of America, Second Edition, pp. 5-6 through 5-14, October 1989.

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